T $\sim$ 90 eV. The ion temperature was measured with an ISP-51 spectrograph crossed with an interferometer, and equaled $T_i \sim$ 1 eV.

Lasing was effected in the described setup in the visible blue-green region at the singly-ionized argon lines 4545, 4579, 4609, 4658, 4880, 4965, 5017, and 5145 Å. The measured divergence of the light beam did not exceed 40". The plasma parameters (electron and ion temperature, density) were regulated by varying the beam parameters (current, energy) and the pressure in the plasma chamber.

Figures 2 and 3 show respectively the emission intensity as functions of the beam current and of the pressure in the plasma chamber. The maximum coherent-emission intensity at 8×10^{-4} - 2×10^{-3} mm Hg (Fig. 3) coincides with the maximum intensity of the high-frequency oscillations excited upon collective interaction between the electron beam and the plasma, and with the maximum of the electron and ion temperature. This correlation is explained by the fact that the rise in the electron and ion temperatures is due to the electric field excited as a result of the instability development. The optimal value of the magnetic field intensity on the plasma-chamber axis was 1.5 kOe. The duration of the generation pulse at the 4880 Å line was τ = 30 μsec, and the pulse power reached 100 W. It should be noted that the lasing was produced in tubes of 20 mm diameter,

Fig. 3. Intensity of coherent emission (in relative units) vs. pressure.

and the generation power did not change appreciably when tubes with larger diameters, up to 85 mm, were used.

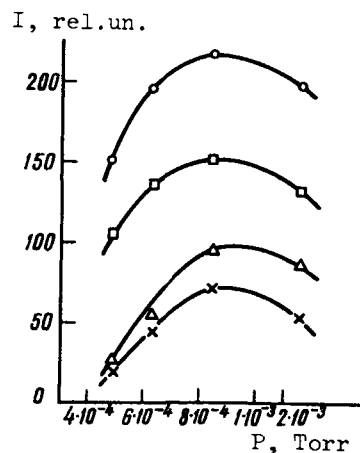Our future investigations call for increasing the generation power, broadening the range of generated lines, and a detailed investigation of the inversion mechanism in the plasma-beam discharge.

[1]   S. G. Kulagin, V. M. Likhachev, E. V. Markuzov, M. S. Rabinovich, and V. M. Sutovskii, ZhETF Pis. Red. 3, 12 (1966) [JETP Lett. 3, 6 (1966)].
[2]   Ya. B. Fainberg, Atomnaya energiya 6, 431 (1959) and 11, 313 (1961).
[3]   A. K. Berezin, G. P. Berezina, L. I Bolotin, Yu. M. Lyapkalo, and Ya. B. Fainberg, in: Fizika plazmy i problemy upravlyaemogo sinteza (Plasma Physics and Problems of Controlled Fusion), No. 3, AN UkrSSR, 1963, p. 125.

PHOTOEFFECT ON NEGATIVE CHARGES IN LIQUID HELIUM

I. A. Fomin
Institute of Theoretical Physics, USSR Academy of Sciences
Submitted 16 October 1967
ZhETF Pis'ma 6, No. 11, 960-963 (1 December 1967)

Results of experimental observation of the photoeffect on negative charges in liquid helium were recently published [1]. The plot of the photocurrent against the wavelength λ of the incident light consitutes a series of alternating maxima and minima, the positions of which on the experimental curve agree with the theoretical calculations for an electron

in a spherically-symmetrical square well, the depth of which is V_0 = 1.02 eV and whose radius a lies between 21.0 and 21.4 Å. However, the experimental curve has an "extra" maximum (λ = 1.28 μ), located near the threshold of the photoeffect, whose magnitude is much more sensitive to temperature changes than the other maxima; this maximum vanishes almost completely at T = 1.3°K. The authors of [1] propose to attribute the presence of this maximum to the possibility of an electron transition with collapse of the bubble that is produced, as is well known, around the electron in the helium. This explanation cannot be true, since the probability of such a transition should be negligible, owing to the strong difference between the frequencies corresponding to the electron transitions and the bubble-oscillation frequencies, which differ by four orders of magnitude.

The true explanation is apparently as follows: The radius of the bubble is somewhat smaller (the estimates were made for a = 20.3 Å) and then, as seen from the theoretical curve drawn in [1], there exists near the threshold of the photoeffect a maximum whose position coincides approximately with the position of the "extra" maximum on the experimental curve. We shall show that with increasing temperature the radius of the bubble increases and all the maxima and minima shift towards lower energies. The magnitude of the maximum closest to the threshold should in this case decrease, for the cross section of the photoeffect tends to zero when the threshold is approached. Numerical estimates offer evidence in favor of such an explanation.

The bubble radius a is connected with the surface-tension coefficient of helium α by the formula $a^4 = \hbar^2 \xi_1^2 / 8\pi m\alpha$, where ξ_1 is the first root of the equation $\xi \cot \xi = -\eta$, $\eta^2 + \xi^2 = 2mV_0 a^2/\hbar^2$, and in our case ($V_0$ = 1.02 eV, a = 20.3 Å) ξ_1^2 = 7.84. α decreases with temperature in accordance with the law derived by Atkins [2]. Using this law and recognizing that $\delta a/a = 4\delta\alpha/\alpha$, we have:

$$\frac{\delta a}{a} \approx 0{,}033 \, \frac{\rho^{2/3} T^{7/3}}{\hbar^{4/3} \alpha_0^{2/3}}.$$

Here ρ denotes the density of the helium in g/cm³ and T the temperature in ergs. When the temperature is increased from 0.7 to 1.3°K we have $\delta a/a$ = 1.4 x 10^{-2}, corresponding to an increase of the bubble radius by 0.28 Å.

The photocurrent is proportional to the cross section of the photoeffect on the "electron inside the bubble" system. The cross section for the photoeffect on a charge in a square potential well was calculated by Breit and Condon [3]:

$$\sigma = \frac{8\pi}{3} \frac{e^2}{\hbar c} \frac{a^2 \epsilon^3}{n_1^2 (E+\epsilon)^3} \left(\frac{E}{\epsilon}\right)^{3/2} \frac{\gamma^2 \xi_1^2 (\sin\xi_E / \xi_E - \cos\xi_E)^2}{(1+\eta_1)[\xi_E^2 \eta_E^2 \sin^2\xi_E + (\gamma^2/\xi_E \sin\xi_E + \eta_E^2 \cos\xi_E)^2]}.$$

The notation here is as follows: E - energy of the electron knocked out of the well; $-\epsilon$ -

ground-state energy, $\eta_1^2 = 2m\epsilon a^2/\hbar^2$, $\gamma^2 = 2mV_0 a^2/\hbar^2$, $\xi_E^2 = 2m(V_0 + \epsilon)c^2/\hbar^2$, $\eta_E^2 = 2mEa^2/\hbar^2$, and e, $\hbar$, c, and m are universal constants.

The rate of change of the height of the maximum with varying well radius is characterized by the derivative

$$\left(\frac{d\sigma}{da}\right)_{E_{max}} = \left(\frac{\partial\sigma}{\partial a} + \frac{\partial\sigma}{\partial E}\frac{dE_{max}}{da}\right)_{E_{max}} = \left(\frac{\partial\sigma}{\partial a}\right)_{E_{max}}.$$

Calculations for the maximum closest to the threshold yield in our case the very large quantity

$$\frac{1}{\sigma}\frac{\partial\sigma}{\partial a} \simeq -\frac{82}{a}.$$

When the radius changes by 0.28 $\overset{\circ}{A}$, we get $\delta\sigma/\sigma \simeq -1.1$, i.e., the cross section changes by an amount of the order of the cross section itself. The values of the other maxima are less influenced by the change in radius; for the second maximum from the threshold (the principal maximum) we have

$$\frac{1}{\sigma}\frac{\partial\sigma}{\partial a} \simeq \frac{8,2}{a},$$

i.e., $\delta\sigma/\sigma = 0.11$, and for the third maximum

$$\frac{1}{\sigma}\frac{\partial\sigma}{\partial a} \simeq \frac{11,5}{a},$$

$\delta\sigma/\sigma \simeq 0.16$ at $\delta a = 0.28$ $\overset{\circ}{A}$. That is to say, both maxima increase slightly and are shifted to the left - the second by 0.04 eV and the third by 0.06 eV.

A good check on the proposed explanation may be provided by experiments analogous to [1], but with pressure applied. A pressure of 9.1 cm Hg would decrease the bubble radius by an amount equal to the increase due to a temperature rise from 0.7 to 1.3°K, and the maximum near the threshold should reappear.

We disregarded in our analysis the fluctuations of the bubble radius, although they are quite large. If we assume that the bubble changes in volume, remaining spherical, then we obtain for the radius fluctuations, from thermodynamic theory, $\overline{(\delta a)^2} = T/32 \pi a$ at $T = 1°K$ and $\sqrt{\overline{(\delta a)^2}} \simeq 2.4 \times 10^{-9}$ cm. This is approximately equal to the calculated temperature expansion. However, allowance for the fluctuations does not greatly influence the result, since the fluctuations lead to a change in the positions of the maxima of the cross section only in second order in $\delta a/a$, whereas the change in the equilibrium value of the radius produces a first-order effect.

The line broadening due to the fluctuations of the radius will cause the minima of the cross section to differ from zero, but their magnitude still remains very small. The

ratio of the cross section at the 1.66 eV minimum to the section at the principal maximum should be ~5 x 10^{-3} at T = 1°K, and the ratio at the 2.48 eV minimum should be ~2 x 10^{-3}. These ratios are much larger on the experimental curve.

The author is grateful to L. P. Pitaevskii for useful discussions.

[1]   J. A. Northby and T. M. Sanders, Phys. Rev. Lett. 18, 1184 (1967).
[2]   K. R. Atkins, Canad. J. Phys. 31, 1165 (1953).
[3]   G. Breit and E. U. Condon, Phys. Rev. 49, 904 (1936).

Detailed calculations (performed with V. I. Truten') have shown that the inequalities (5) and (9), which are based on preliminary estimates, are incorrect, and they should be replaced by the equalities $B = 3\pi/2$ and $Z_3 = 0$. Equation (4) has thus a unique solution.

In spite of the vanishing of Z_3, it is possible to obtain a finite renormalized charge in the theory under consideration, unlike in [3], by letting the bare charge to to infinity.